Calculation of PM Profiles

PM_{10} and $PM_{2.5}$ air quality profile databases were compiled for all simulations performed as part of the Section 812 prospective analysis. For each of the particulate species, these data bases contained the number, the arithmetic mean, the median, the annual second highest, and the 2.5 to 97.5 percentiles (in increments of five) of the daily (as available) concentrations. The profiles are reported at the monitor level and include 2048 site locations.

The histograms in Figures C-21a through C-24b illustrate the distribution of ratios for the annual average monitor-level PM_{10} and $PM_{2.5}$ concentrations corresponding to the 2000 and 2010 simulations. In these figures, ratios greater than one indicate that the future-year/scenario concentration is greater than the base-year (1990) value, whereas ratios less than one indicate a lower value for the future-year.

The 2000 Pre-CAAA ratios for PM_{10} (Figure C-21a) indicate that the annual average PM_{10} concentrations corresponding to this scenario are higher in some areas and lower in other areas than the base-year (1990) values. The ratios generally range from approximately 0.95 to 1.1, but also include some higher values. In contrast, the ratios corresponding to the 2000 Post-CAAA simulation (Figure C-21b) are generally less than or equal to one, with most sites being assigned a ratio consistent with a small decrease in annual average PM_{10} concentration. There are also some lower values.

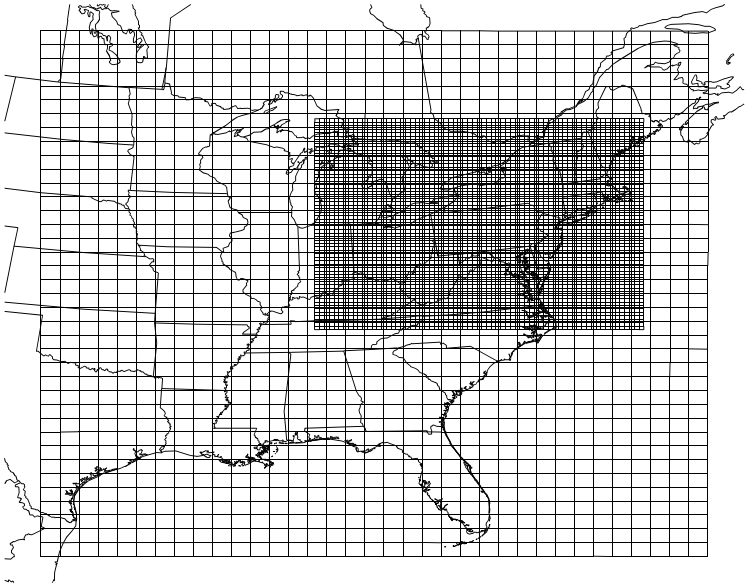
Figure C-22a and C-22b display the distribution of ratios of the future-year-scenario to base-year annual average PM_{10} concentrations for 2010. Compared to the histogram plots for 2000, the ratios are higher for the Pre-CAAA scenario but similar for the Post-CAAA scenario. There is some indication that, by 2010, increases due to growth are limiting the effectiveness of the CAAA measures.

The 2000 Pre-CAAA ratios for $PM_{2.5}$ (Figure C-23a) indicate that the annual average $PM_{2.5}$ concentrations corresponding to this scenario are generally higher than (or equal to) the base-year (1990) values. The ratios generally range from approximately 0.975 to 1.15. In contrast, the ratios corresponding to the 2000 Post-CAAA simulation (Figure C-23b) are generally less than one. In this case, the ratios range from approximately 0.925 to 1.075.

For 2010, the $PM_{2.5}$ ratios (Figures C-24a and C-24b), indicate increases for the Pre-CAAA scenario and mostly decreases for the Post-CAAA scenario. Again, compared to 2000, concentrations for 2010 are higher relative to the base year under the Pre-CAAA scenario and similar to or slightly lower relative to the base year under the Post-CAAA scenario.

For both future years (2000 and 2010), the ratios indicate that the Post-CAAA concentrations (annual average) are lower than the corresponding Pre-CAAA values. This is illustrated in Figures C-25a through C-26b. The smaller ratios for 2010 reflect larger differences between the Pre- and Post-CAAA scenarios.

Figure C-14
80-km RADM Domain



Note: Nested 20-km grid estimates were not used to generate final results, but were used in evaluating the reasonableness of results.

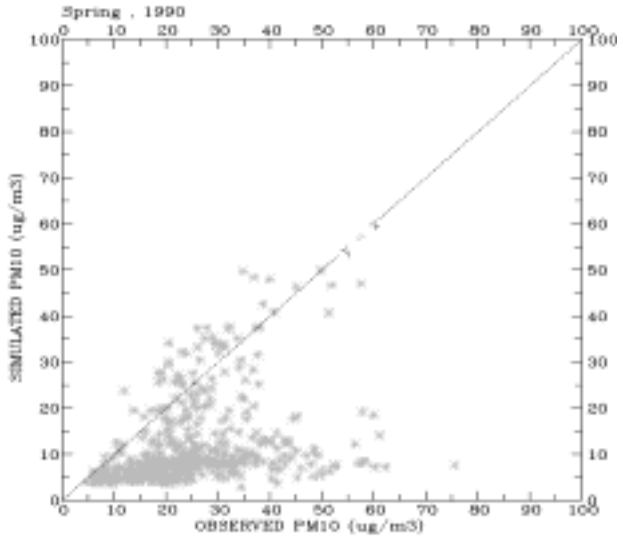


Figure C-15. Comparison of simulated and observed seasonal PM10 concentration (ug/m3) for REMSAD for the western U.S.: spring 1990

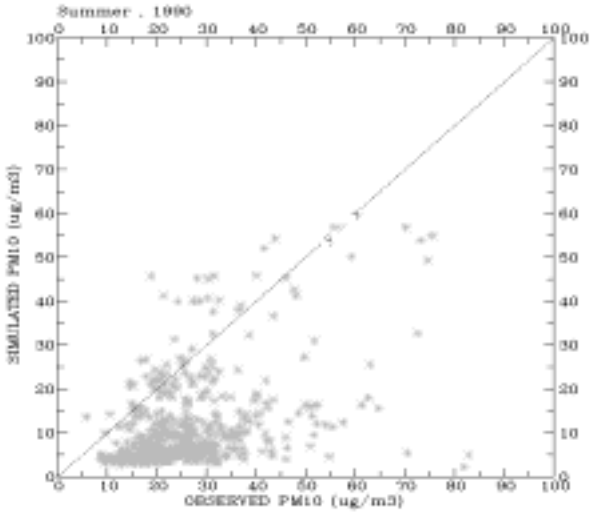


Figure C-16. Comparison of simulated and observed seasonal PM10 concentration (ug/m3) for REMSAD for the western U.S.: summer 1990

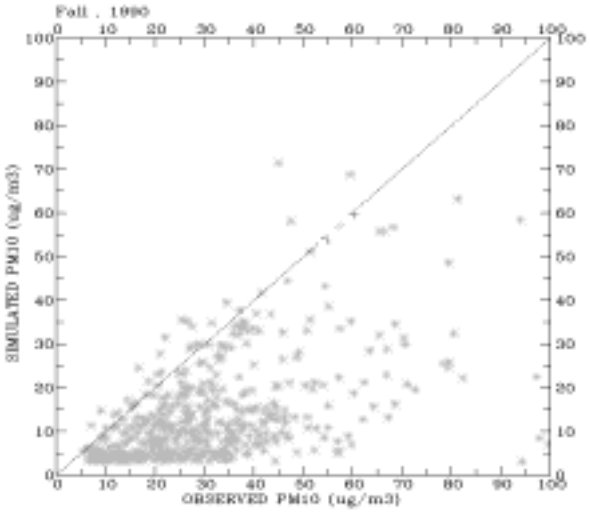


Figure C-17. Comparison of simulated and observed seasonal PM10 concentration (ug/m3) for REMSAD for the western U.S.: fall 1990

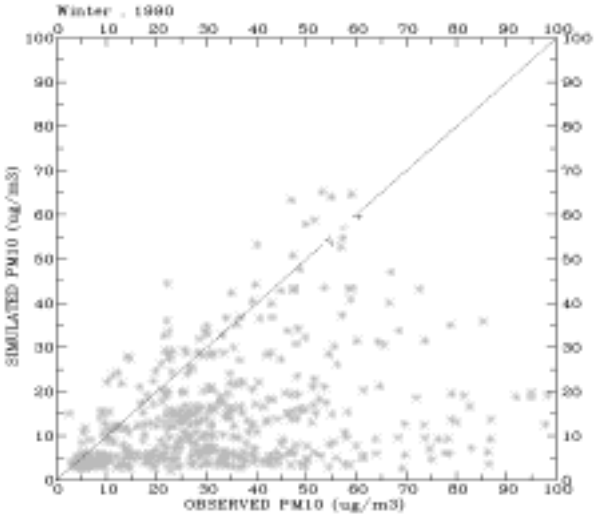


Figure C-18. Comparison of simulated and observed seasonal PM10 concentration (ug/m3) for REMSAD for the western U.S.: winter 1990

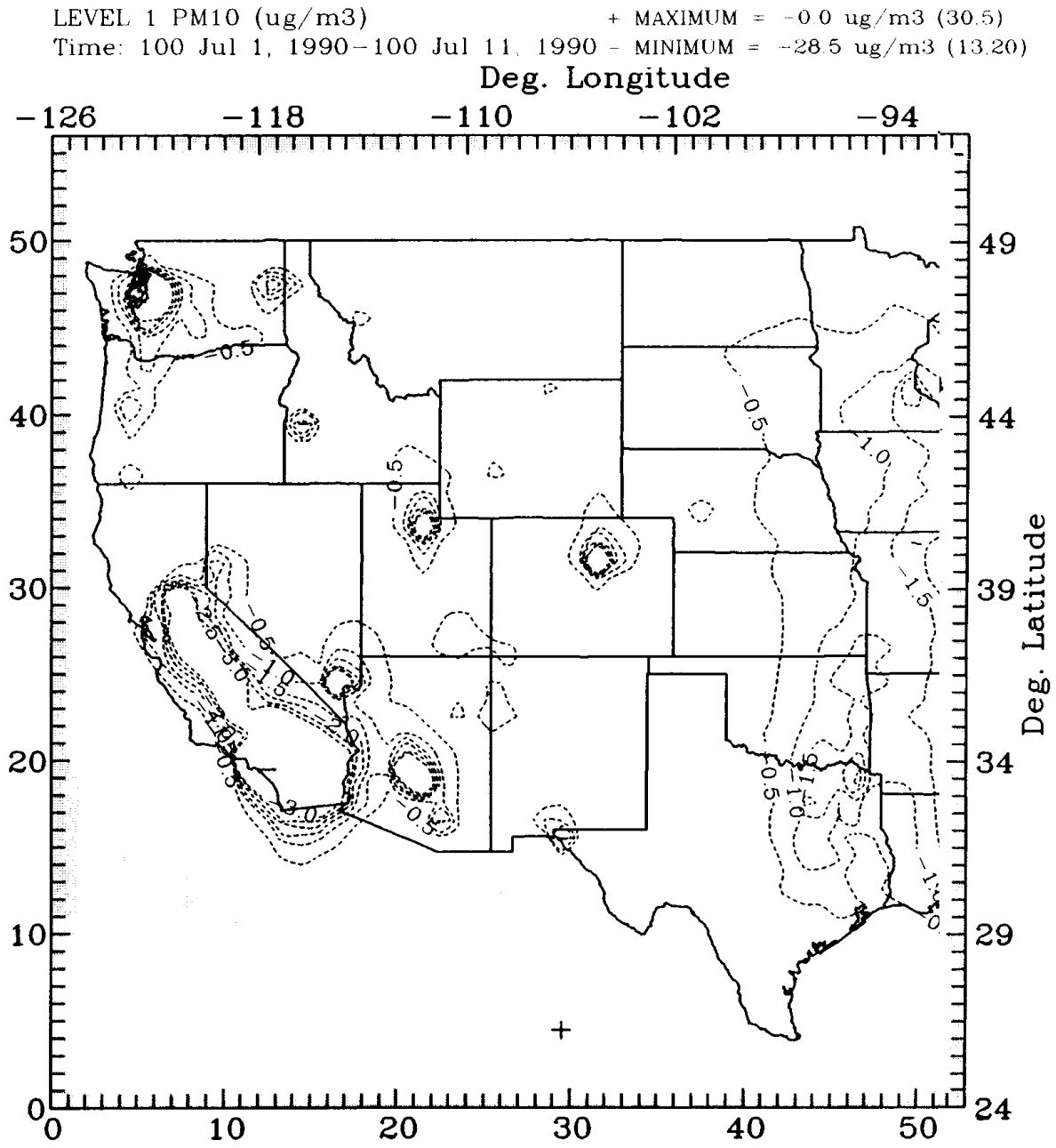


Figure C-19. Difference in seasonal average PM10 concentration (ug/m3) for the summer REMSAD simulation period (1-10 July 1990) for 2010: post-CAAA90 minus pre-CAAA90

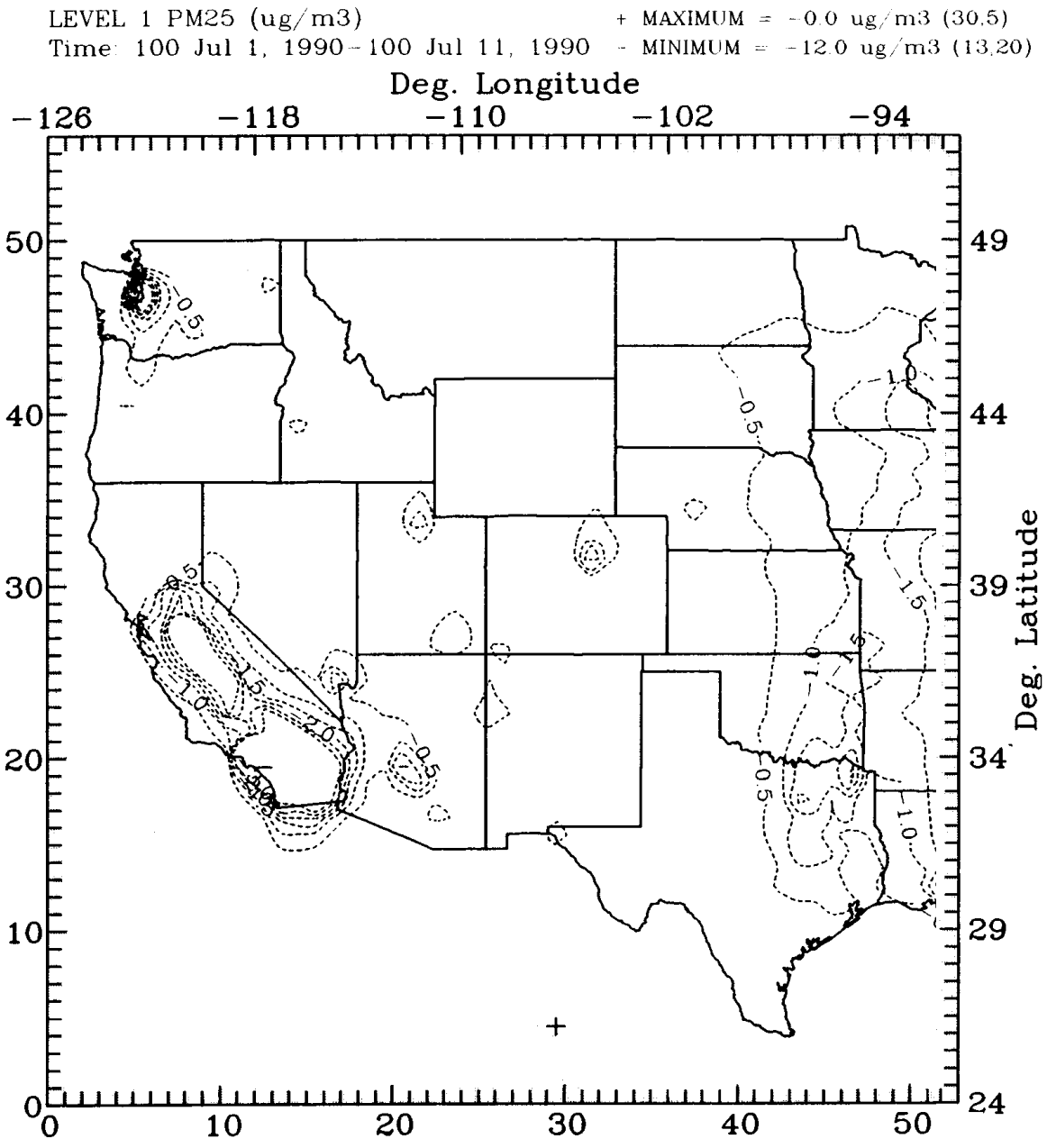


Figure C-20. Difference in seasonal average PM25 concentration (ug/m3) for the summer REMSAD simulation period (1-10 July 1990) for 2010: post-CAAA90 minus pre-CAAA90

Figure C-21a. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average PM_{10} Concentration: 2000 Pre-CAAA / 1990 Base-Year

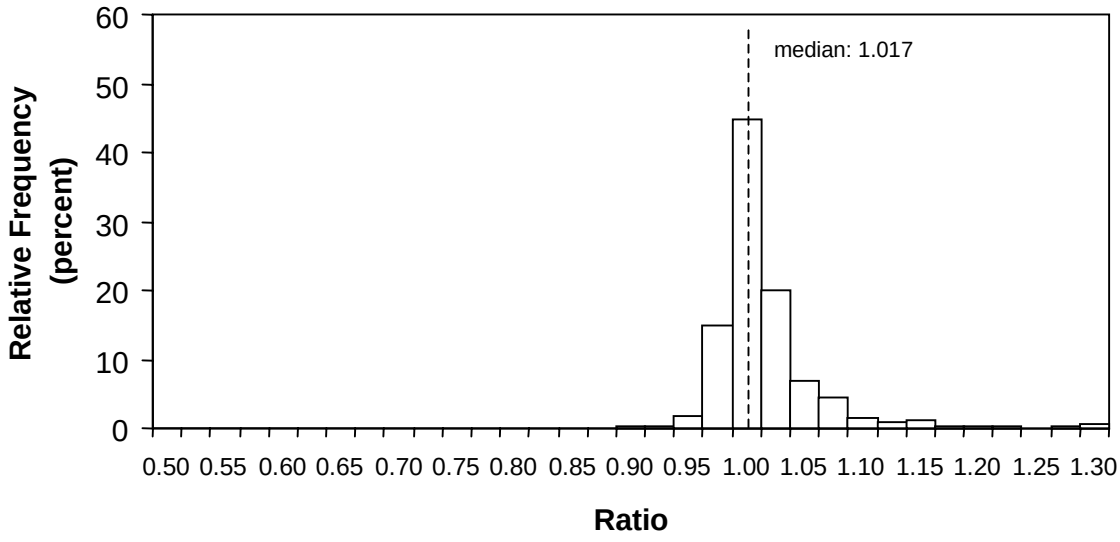


Figure C-21b. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average PM_{10} Concentration: 2000 Post-CAAA / 1990 Base-Year

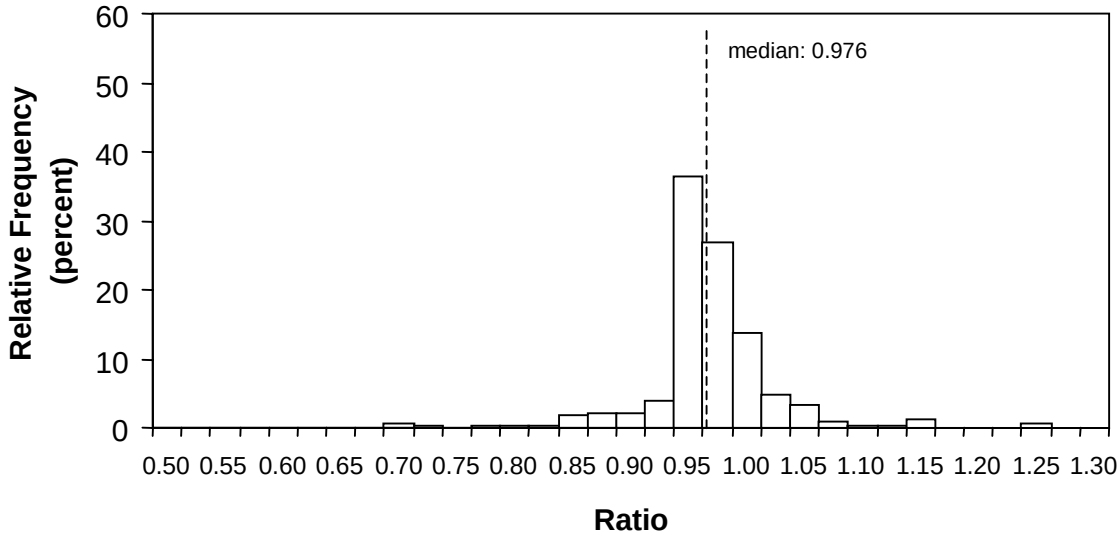


Figure C-22a. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average PM_{10} Concentration: 2010 Pre-CAAA / 1990 Base-Year

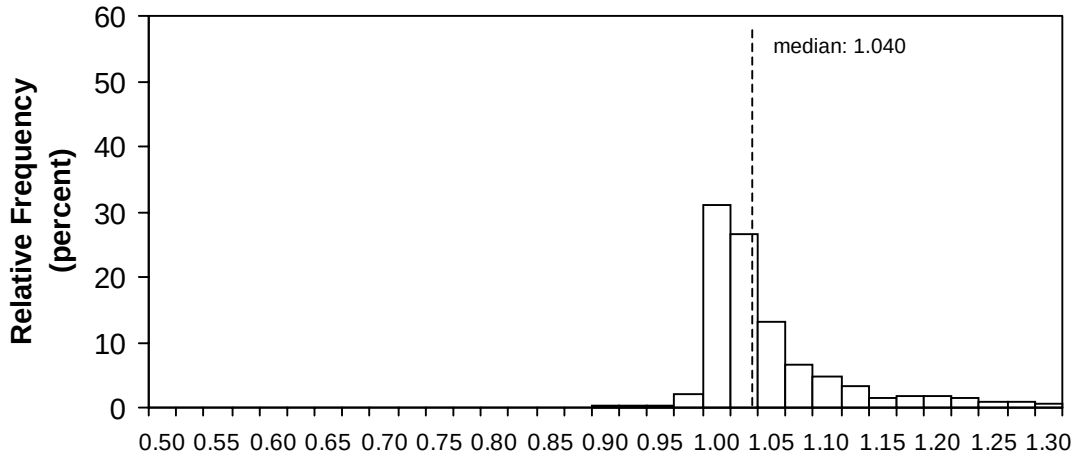


Figure C-22b. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average PM_{10} Concentration: 2010 Post-CAAA / 1990 Base-Year

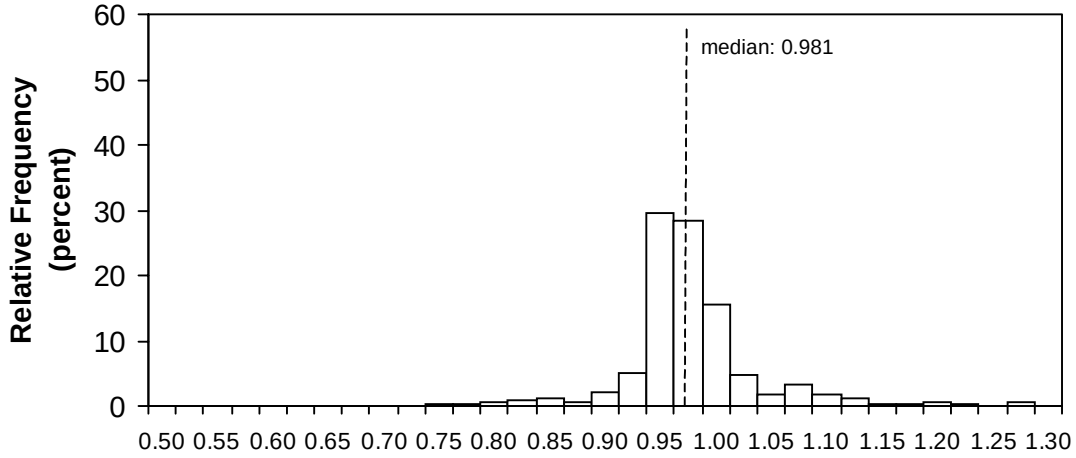


Figure C-23a. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average $PM_{2.5}$ Concentration: 2000 Pre-CAAA / 1990 Base-Year

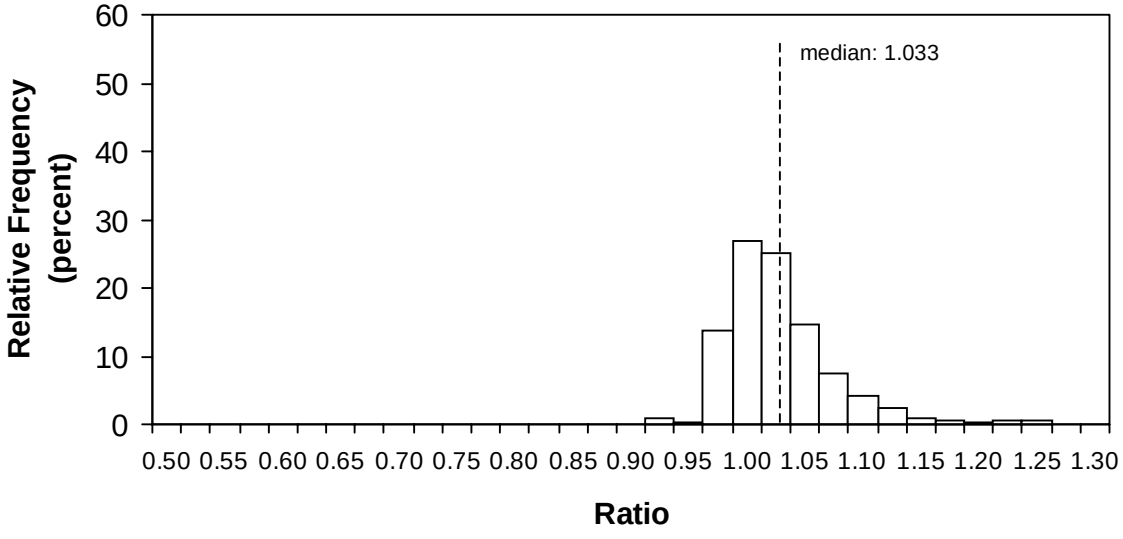


Figure C-23b. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average $PM_{2.5}$ Concentration: 2000 Post-CAAA / 1990 Base-Year

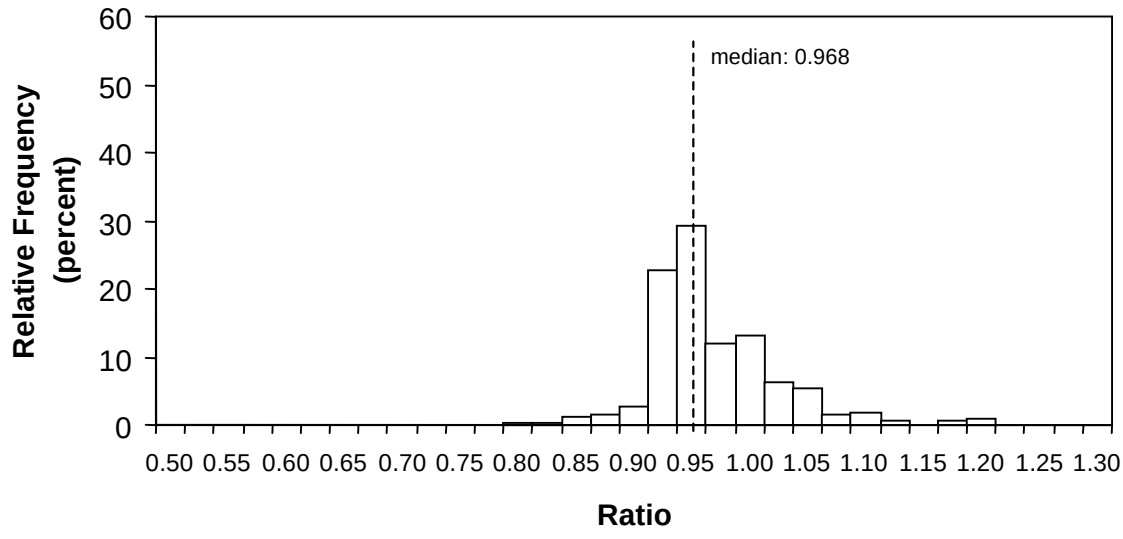


Figure C-24a. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average $PM_{2.5}$ Concentration: 2010 Pre-CAAA / 1990 Base-Year

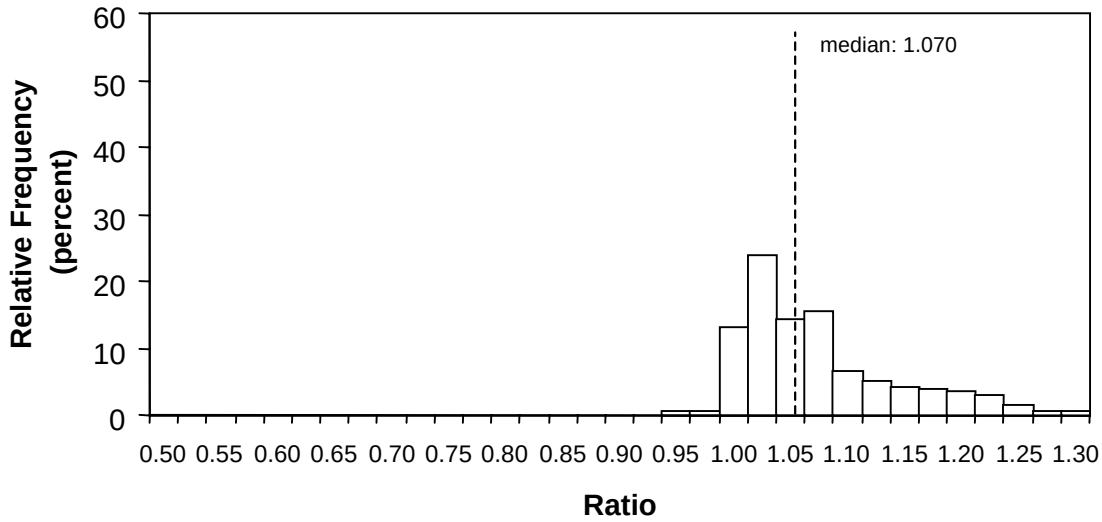


Figure C-24b. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average $PM_{2.5}$ Concentration: 2010 Post-CAAA / 1990 Base-Year

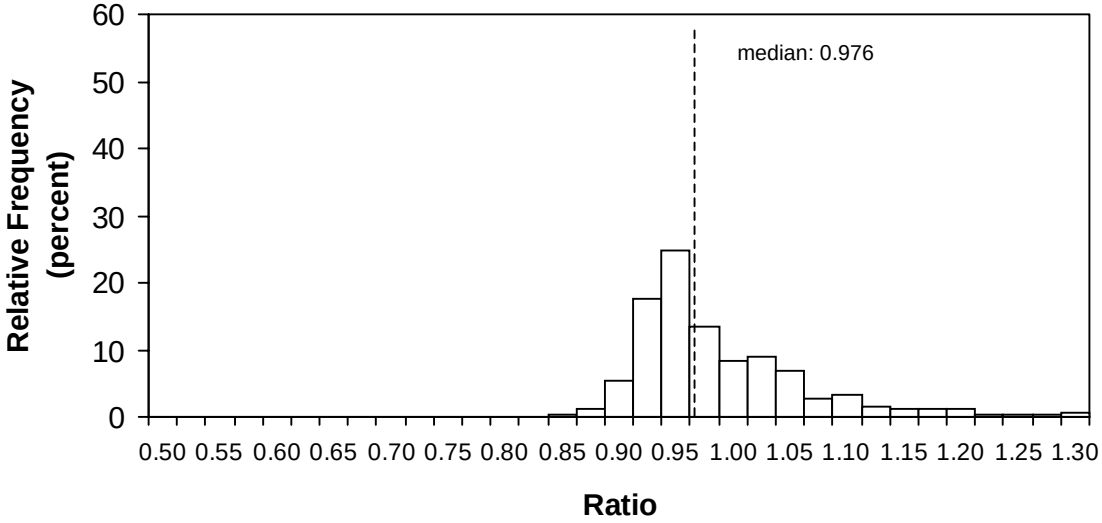


Figure C-25a. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average PM_{10} Concentration: 2000 Post-CAAA / 2000 Pre-CAAA

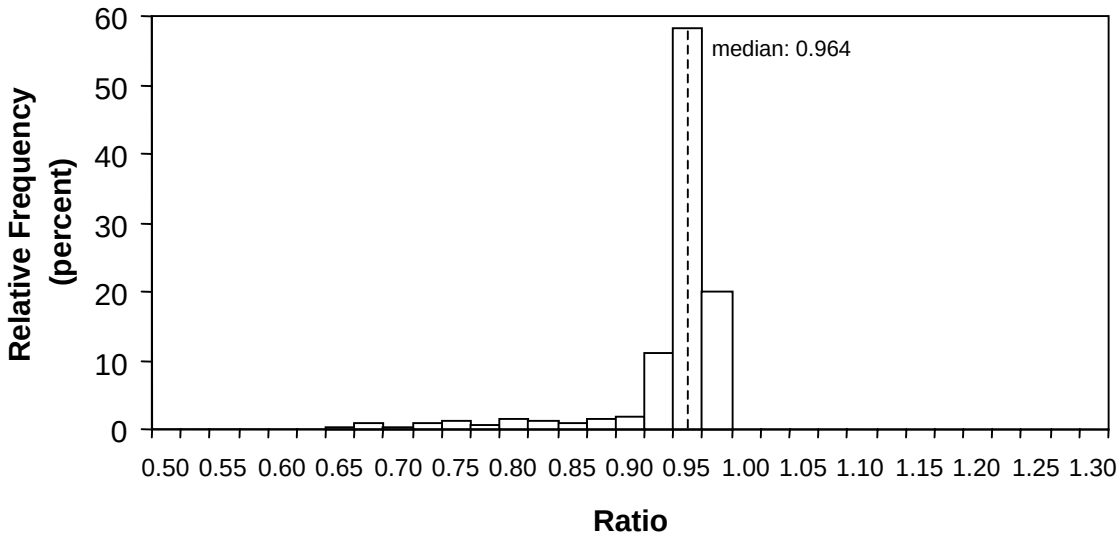


Figure C-25b. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average PM_{10} Concentration: 2010 Post-CAAA / 2010 Pre-CAAA

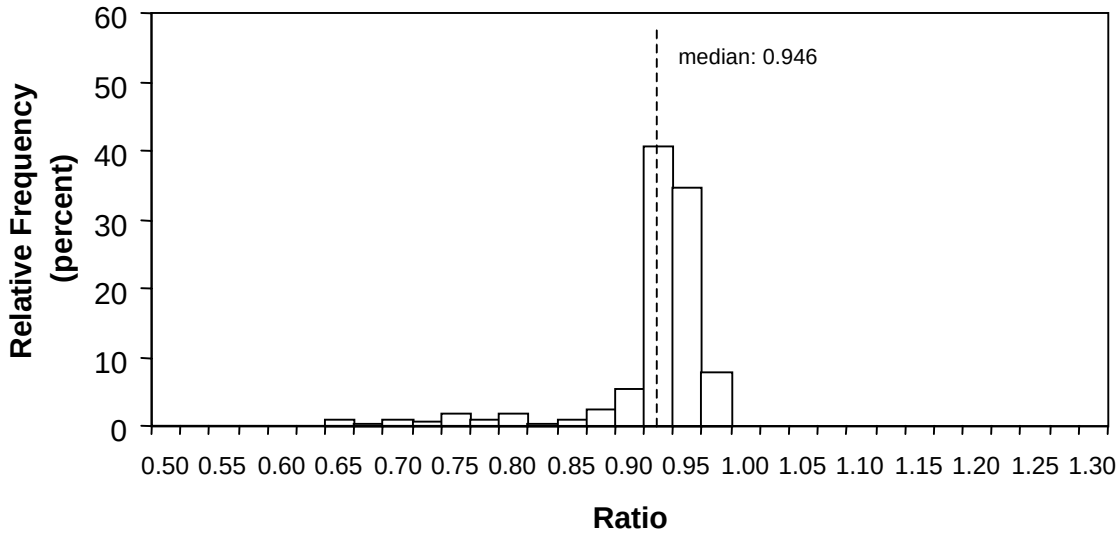


Figure C-26a. Distribution of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average $PM_{2.5}$ Concentration: 2000 Post-CAAA / 2000 Pre-CAAA

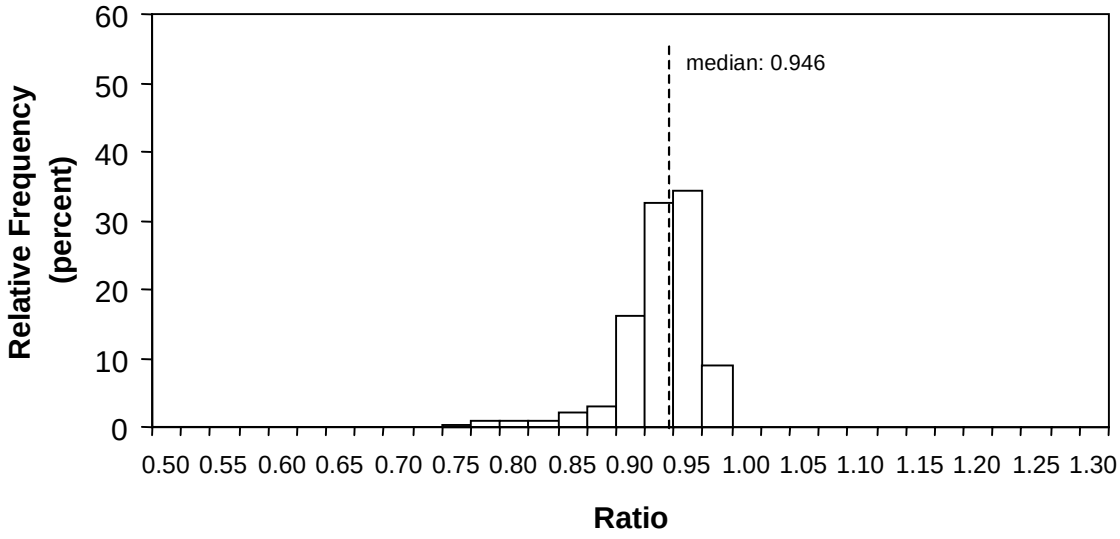
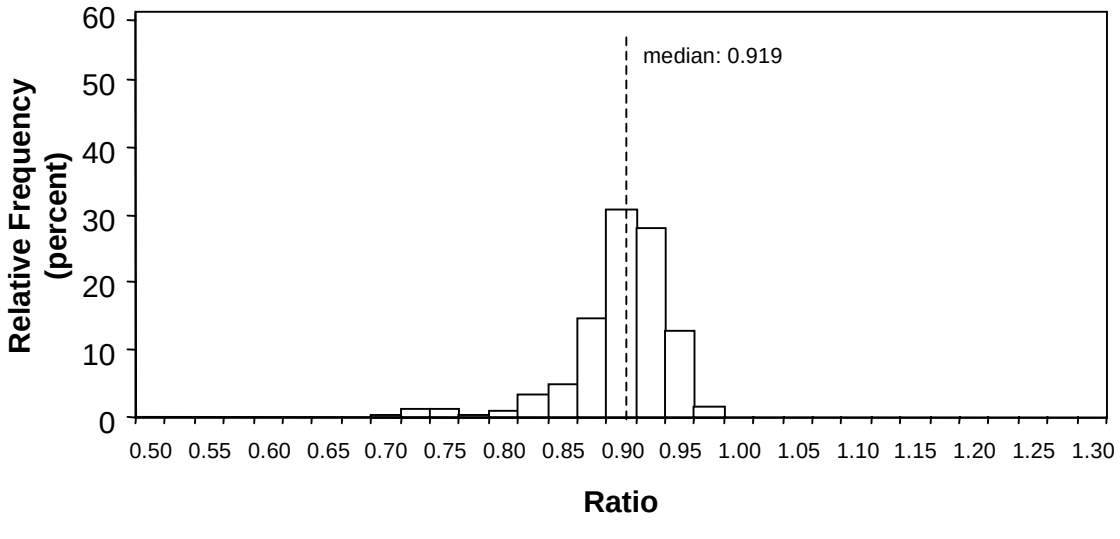


Figure C-26b. Description of Combined RADM/RPM- and REMSAD-Derived Monitor-Level Ratios for Annual Average $PM_{2.5}$ Concentration: 2010 Post-CAAA / 2010 Pre-CAAA



Estimating the Effects of the CAAA on Visibility

Light traveling through the atmosphere is "absorbed" and "scattered" by gases and suspended particles. These distortion processes contribute to total atmospheric light extinction which, in turn, causes visibility degradation. To characterize and ultimately quantify the effect of changes in emissions on visibility, an understanding of the concentrations and types of gaseous particulate constituents in the air is necessary.

The influence of gaseous absorption on light extinction is almost negligible. Gaseous scattering has a larger impact, although this impact is generally not as significant as either particulate absorption or scattering. Together the influence of all four of these light distortion processes is expressed quantitatively as the light extinction coefficient, b_{ext}. In this analysis RADM/RPM and REMSAD are both used to calculate b_{ext}.

RADM/RPM and Visibility

RADM/RPM estimates b_{ext} in the eastern U.S., for each emissions scenario (1990 base year, 2000 Pre-CAAA, 2000 Post-CAAA, 2010 Pre-CAAA, and 2010 Post-CAAA), by combining the influences of particle scattering and absorption and incorporating the effect of scattering caused by water. The fine particles estimated by RADM/RPM (including their associated water) are secondary particulates: sulfates, nitrates, associated ammonium, and organics. Absorption by carbon particles is not included in the model's calculations, nor is extinction resulting from primary particles. By not including these latter influences, RADM/RPM may underestimate the effects of air pollution on visibility.

RADM/RPM, along with generating atmospheric light extinction values, calculates "visual range" and deciview (dV), both measures that quantify visibility. The former, VR, is related to the light extinction coefficient by the following equation:

$$VR(\text{meters}) = 3.912/b_{ext},$$

where b_{ext} is in inverse meters. The latter measure of visibility, dV, and the related DeciView Haze Index are improved indicators of the clarity of the atmosphere. This index more accurately captures the relationship between air pollution and human's perception of visibility than does VR or b_{ext} (Pitchford and Malm, 1994). A deciview is defined by the equation:

$$dV = 10\ln(b_{ext}/10),$$

where b_{ext} is expressed in inverse megameters.

The DeciView Haze Index has a value of approximately zero when the light extinction coefficient is equal to the scattering coefficient for particle-free air. A roughly 10 percent increase in b_{ext} translates to a one unit change in dV. Since the apparent change in visibility is related to a percent change in b_{ext}, equal changes in dV correspond to approximately equally perceptible changes in visibility. Research indicates that, for most observers, a "just noticeable change" in visibility corresponds to an increase or decrease of about one to two dV units. An increase in the deciview level translates to degradation of visibility, while a decrease represents and improvement.

RADM/RPM Modeling Results

For this analysis, under the 1990 base year and future year emissions scenarios, the annual mean daylight hour b_{ext}, VR, and dV were estimated for each RADM/RPM grid cell. A summary of 1990 and 2010 deciview levels for selected cities, metropolitan areas, and national parks is provided in Table C-13. These deciview estimates show that under the Pre-CAAA scenario visibility degradation is expected throughout much of the eastern U.S. Comparison of 1990 base year and 2010 Post-CAAA estimates, however, indicates that with the implementation of CAAA related measures, a perceptible improvement in visibility can be expected.

Table C-13
Comparison of Visibility in Selected Eastern Cities, Metropolitan Areas, and National Parks

		Mean Annual Deciview		
Area Name	**State**	**1990 Base Year**	**2010 Pre-CAAA**	**2010 Post-CAAA**
Acadia NP	ME	11.1	12.0	10.4
Atlanta Metro Area	GA	20.9	22.8	20.0
Boston Metro Area	MA	13.2	14.0	11.9
Chicago Metro Area	IL	17.5	19.1	17.0
Columbus	OH	16.5	17.7	15.1
Detroit Metro Area	MI	16.0	18.5	15.3
Everglades NP	FL	7.6	9.2	6.9
Great Smoky Mtns. NP	TN	20.4	22.3	19.6
Indianapolis	IN	20.1	21.1	19.0
Little Rock	AR	15.0	17.2	15.1
Milwaukee Metro Area	WI	15.6	18.4	15.3
Minn.-St. Paul Metro Area	MN	10.1	12.4	10.3
Nashville	TN	20.4	21.5	19.0
New York City Metro Area	NY/NJ	15.2	18.0	13.9
Pittsburgh Metro Area	PA	15.8	16.9	14.2
St. Louis Metro Area	MO	16.5	17.8	16.0
Shenandoah NP	VA	16.5	17.8	15.2
Syracuse	NY	12.4	13.2	11.5
Washington, DC Metro Area	DC/VA/MD	17.5	19.2	16.3

*For cities, metro areas, or national parks not contained by a single RADM/RPM grid cell, the visibility measure presented in this table is a weighted average of the mean annual deciview level from each of the grid cells that together completely contain the selected area. Weighting is based upon the spatial distribution of an area over the various grid cells.

REMSAD and Visibility

REMSAD was used to estimate the effect of changes in emissions on visibility for the western U.S. This model calculates light extinction coefficients based upon estimates of the gridded ground-level concentrations of the following species – sulfate (NH4S+GSO4+ASO4), nitrate (NH4N+PNO3), NO2, SOA, POA, PEC, PMfine and PMcoarse (refer to Table C-8 for a description of these species abbreviations). The contribution from each of these species is adjusted based on the extinction efficiency of each and, in the case of sulfate, nitrate and SOA, an adjustment dependent on the relative humidity. The total extinction coefficient is then given by:

b_{ext} = 10.+ 0.17*NO2 + f_{so4}(RH)*sulfate + f_{no3}(RH)*Nitrate + f_{soa}(RH)*SOA +6.2*POA + 10.5*PEC + PMFINE + 0.6*PMCOARSE

where the constant value of 10.0 is the contribution to the scattering coefficient for particle-free air (Rayleigh scattering). REMSAD generated b_{ext} values are then converted to deciviews.

REMSAD Modeling Results

Visibility estimates and change in visibility were calculated for each of the future-year scenarios for use in the effects analysis. Figure C-27 illustrates 1990 base year deciview levels for the western U.S. This map shows that visibility is poorer in the region of California extending from San Francisco southward to Los Angeles, the Pacific Northwest, and larger metropolitan areas such as Denver, CO; Albuquerque, NM; and Phoenix, AZ. Most noticeable is the comparatively high deciview level in the Los Angeles region.

Figures C-28 and C-29 illustrate the difference between 2010 Pre-CAAA and 1990 base year estimates and the difference between 2010 Post-CAAA and 1990 base year estimates, respectively. The first of these maps shows that under the Pre-CAAA scenario visibility is expected to remain unchanged between 1990 and 2010 throughout much of the West and actually improve in coastal Oregon and along the western Idaho border. In the larger urban areas, however, perceptible visibility degradation is predicted. Visibility improvement in and around western cities, especially in California, is predicted under the Post-CAAA scenario. Figure C-29 captures these changes and shows that in 2010 improvements in visibility are not expected to be restricted to just the larger urban areas; compared to 1990 base year estimates, Post-CAAA deciview levels are also predicted to be lower throughout much of Washington, Oregon, and Nevada and in sizeable sections of Arizona, Idaho, Utah, and Wyoming.

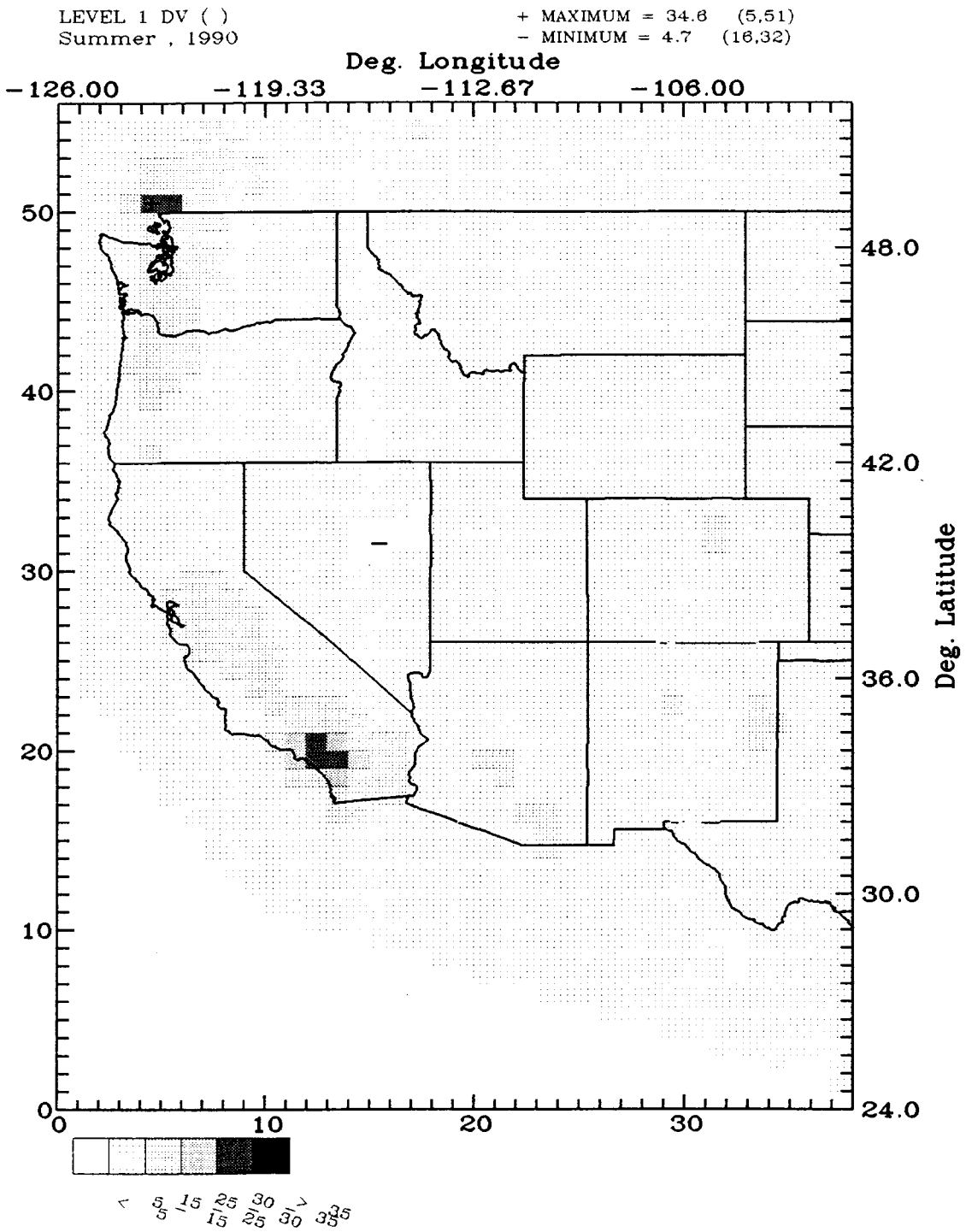


Figure C-27. Seasonal Average Deciview for the summer REMSAD simulation period (1-10 July 1990): base 1990 (western U.S. only)

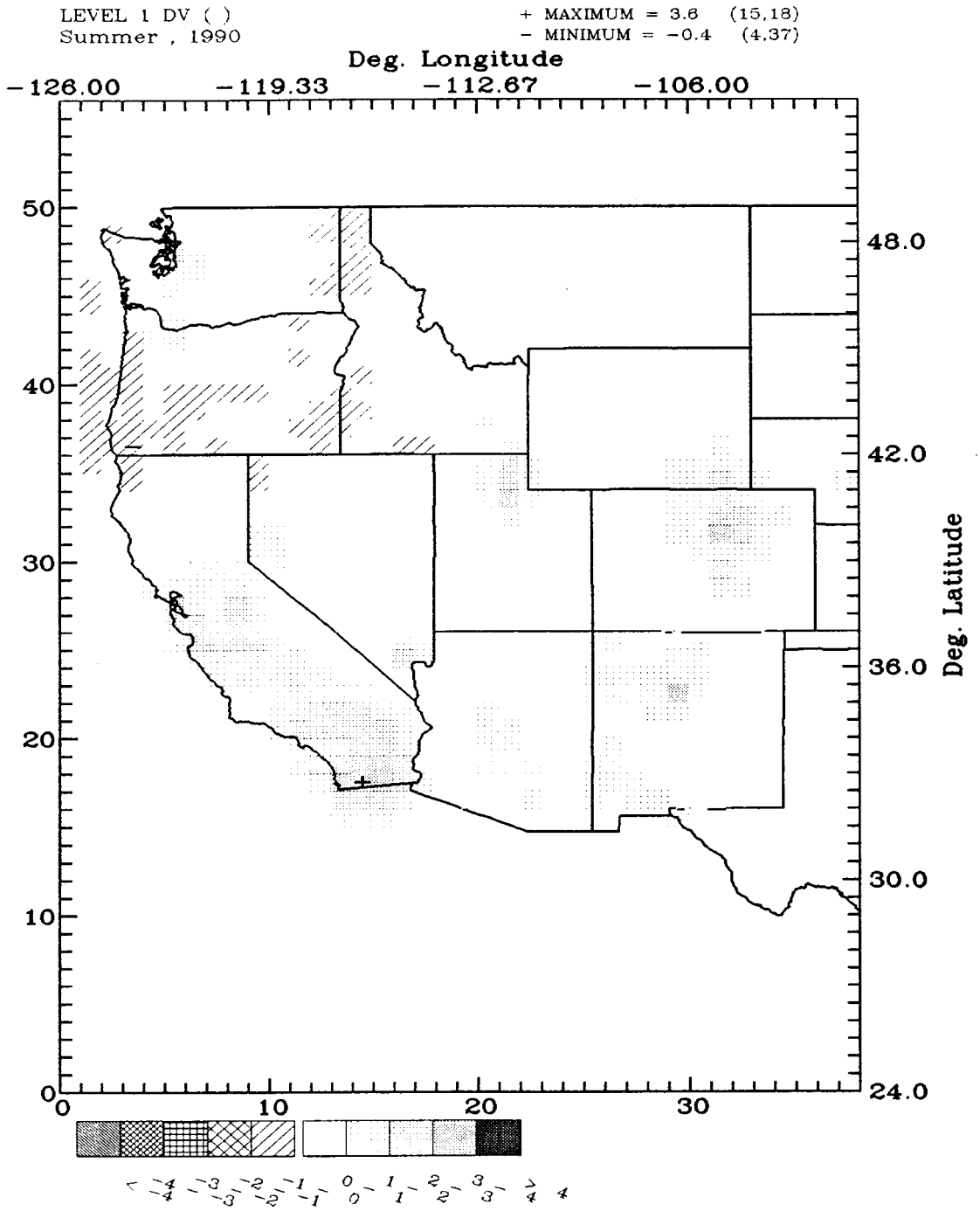


Figure C-28. Difference in seasonal average Deciview for the summer REMSAD simulation period (1-10 July 1990): 2010 pre-CAAA90 minus base 1990 (western United States only)

Acid Deposition

The acid deposition modeling efforts for this analysis focused on estimating the change in ambient concentrations of selected pollutants as a result of changes in emissions. The need to focus on relative changes, rather than absolute predictions, is especially acute when estimating air quality outcomes for pollutants subject to long-range transport, chemical transformation, and atmospheric deposition. The complexity of the relationships between emissions, air concentrations, and deposition is well-described in the following paragraph from the RADM report document developed by Robin Dennis of U.S. EPA's National Exposure Research Laboratory:

> *"Sulfur, nitrogen, and oxidant species in the atmosphere can be transported hundreds to thousands of kilometers by meteorological forces. During transport the primary emissions, SO_2, NO_x, and volatile organic compounds (VOC) are oxidized in the air or in cloud-water to form new, secondary compounds, which are acidic, particularly sulfate and nitric acid, or which add to or subtract from the ambient levels of oxidants, such as ozone. The oxidizers, such as the hydroxyl radical, hydrogen peroxide and ozone are produced by reactions of VOC and NO_x. The sulfur and nitrogen pollutants are deposited to the earth through either wet or dry deposition creating a load of pollutants to the earth's surface... However, the atmosphere is partly cleansed of oxidants through a number of physical processes including deposition (e.g., ozone is removed by wet and dry deposition). Dry deposition occurs when particles settle out of the air onto the earth or when gaseous or fine particle species directly impact land, plants, or water or when plant stomata take up gaseous species, such as SO_2. In wet deposition, pollutants are removed from the atmosphere by either rain or snow. In addition, fine particles or secondary aerosols formed by the gas- and aqueous-phase transformation processes scatter or absorb visible light and thus contribute to impairment of visibility."*[10]

[10] Dennis, R. RADM Report (1995), p. 1.

The complexity and nonlinearity of the relationships between localized emissions of precursors, such as SO_2 and VOCs, and subsequent regional scale air quality and deposition effects are so substantial that advanced modeling is required to accurately estimate the broad-scale impact of changes in emissions on acid deposition. For this analysis, EPA used the Regional Acid Deposition Model (RADM) to estimate acid deposition in the eastern United States.

Overview of the RADM Modeling System

RADM, a three-dimensional Eulerian grid-based model also used in the PM analysis, estimated nitrogen and sulfur deposition for the 1990 base year and each of the future year emissions scenarios. Estimates, expressed in kg/ha, were developed for 2000 and 2010 and calculated for each 80-km RADM grid cell. It is important to note, however, that ammonia deposition, a significant contributor to total nitrogen deposition, was held constant for each of the model runs. This was because livestock farming and other activities that drive ammonia formation and deposition were essentially unaffected by the CAAA-related control programs. A more detailed description of RADM, its domain, and its inputs is provided earlier in this appendix..

RADM Modeling Results

Figures C-30 and C-31 show the 1990 base-year deposition estimates for sulfur and nitrogen respectively. Predictions for both pollutants under the Pre- and Post-CAAA scenarios are displayed in Figures C-32 through C-35. Comparison of the three maps showing sulfur deposition and comparison of the three maps showing nitrogen deposition reveals that for both pollutants annual deposition under the Pre-CAAA scenario is expected to increase between 1990 and 2010. Year 2010 Post-CAAA sulfur and nitrogen deposition projections, however, are not only lower than 2010 Pre-CAAA projections, but also below 1990 base year levels. Together, these maps indicate that between 1990 and 2010 average annual

acid deposition is expected to decrease as a result of the Clean Air Act Amendments.

Noticeable in each of the figures, especially those mapping nitrogen, is an area of high deposition along the Virginia-North Carolina border. This "hot spot" is above Person County, NC, a region with one large and one very large utility plant.[11] Emissions from these plants, particularly NO_x, likely are the source of the high deposition in this area. Person County exhibits the highest base year and future year Pre- and Post-CAAA acid deposition estimates in the entire RADM domain.

Comparison of 2010 Pre- and Post-CAAA emissions in Person County shows that NO_x emissions are expected to be lower in 2010 as a result of the CAAA. This change in emissions, however, translates to a change in acid deposition that is not captured by the maps provided in this section. 2010 Post-CAAA nitrogen and sulfur deposition estimates for this county are 27.2 and 78.0 kg/ha respectively. These figures represent a decrease in nitrogen deposition of 14.0 kg/ha and a decrease in sulfur deposition of 4.5 kg/ha from 2010 Pre-CAAA levels. Compared to the base year, the 2010 Post-CAAA nitrogen deposition estimate for Person County is 4.1 kg/ha lower than 1990 levels, the 2010 Post-CAAA sulfur deposition prediction, however, is 12.9 kg/ha higher.

[11]Under the 2010 Post-CAAA scenario the Mayo (large) and Roxboro (very large) utility plants are predicted to emit 9,400 and 30,100 tons of NO_x per year respectively.

Figure C-29
Annual Sulfur Deposition
1990 Base Case Scenario

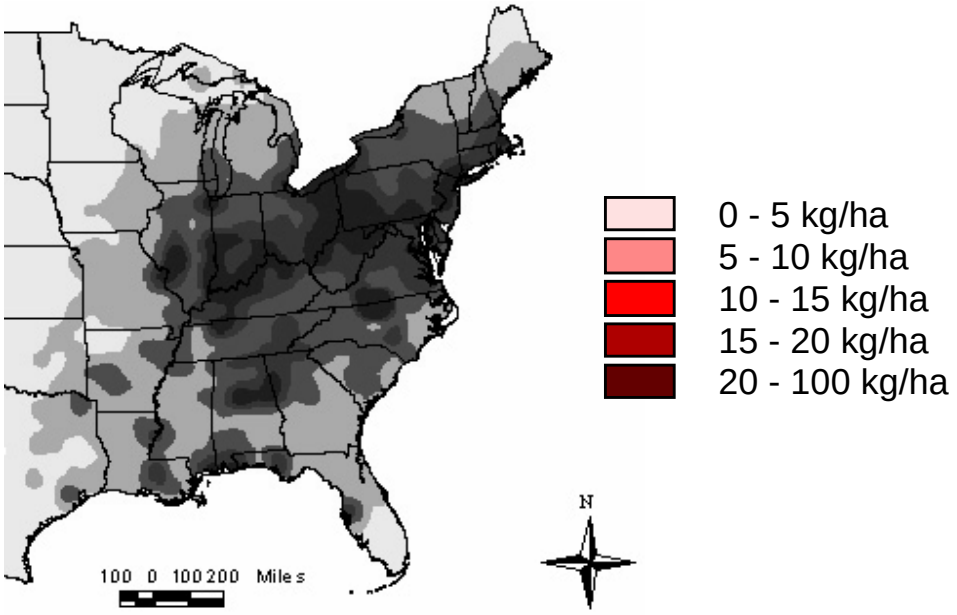


Figure C-30
Annual Nitrogen Deposition
1990 Base Case Scenario

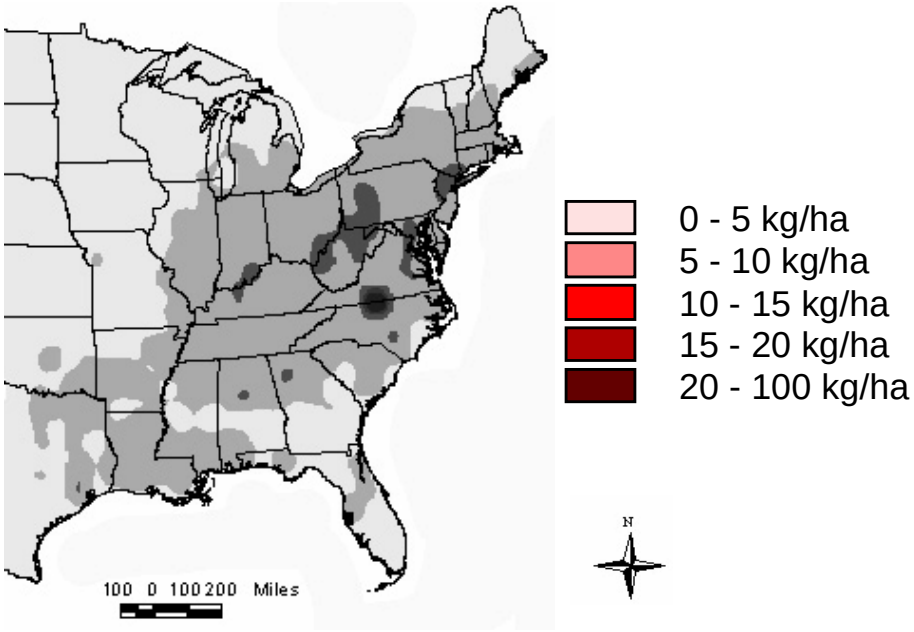


Figure C-31
Annual Nitrogen Deposition
2000 Pre CAAA Scenario

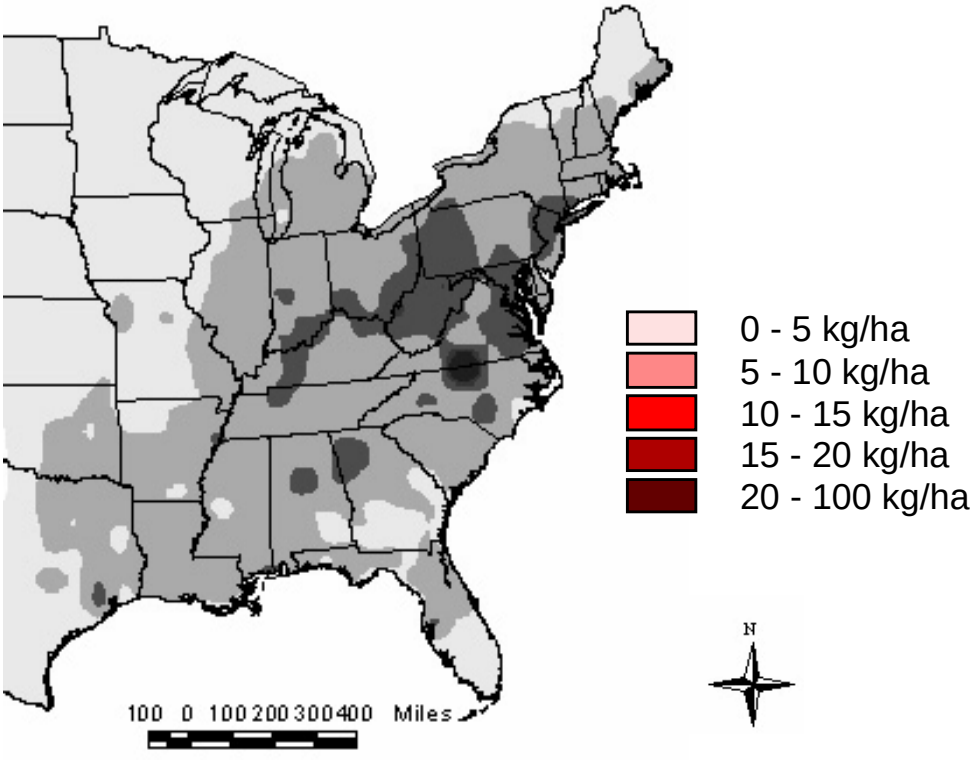


Figure C-32
Annual Sulfur Deposition
2010 Post CAAA Scenario

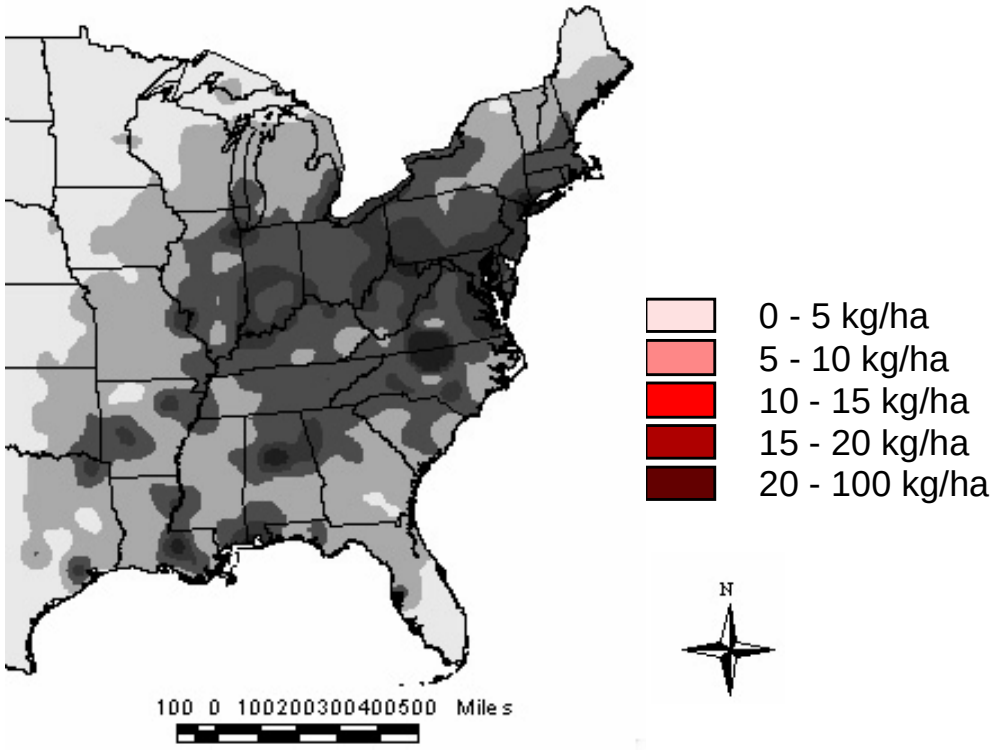


Figure C-33
Annual Nitrogen Deposition
2010 Pre CAAA Scenario

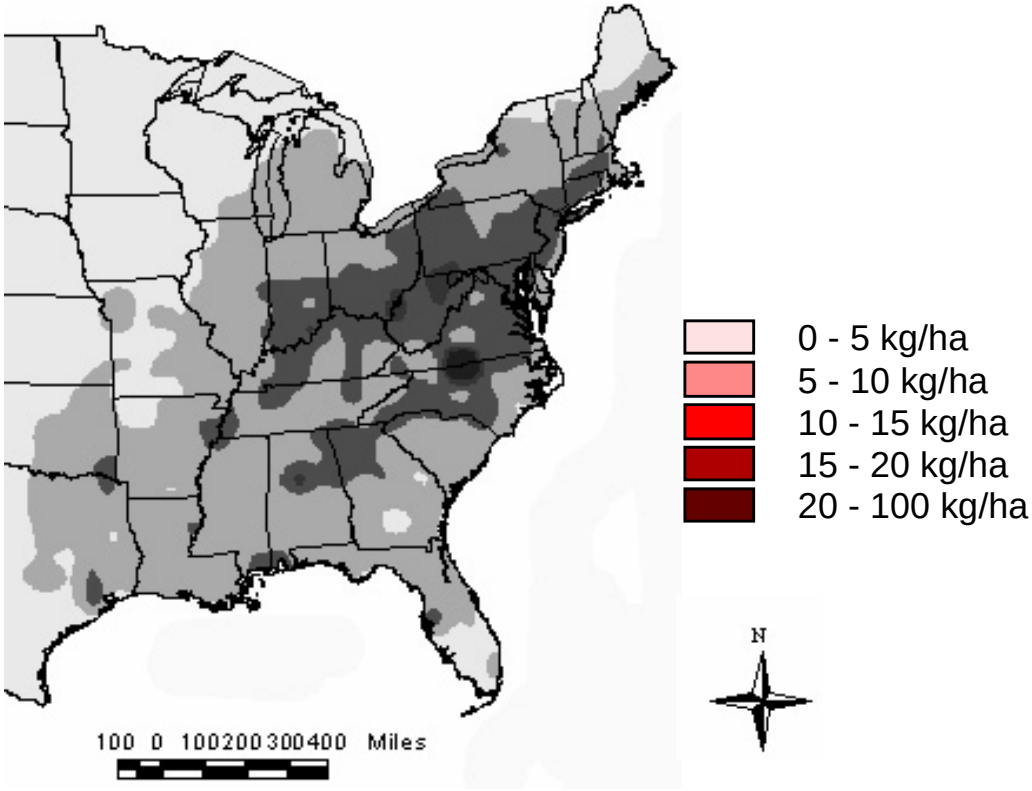
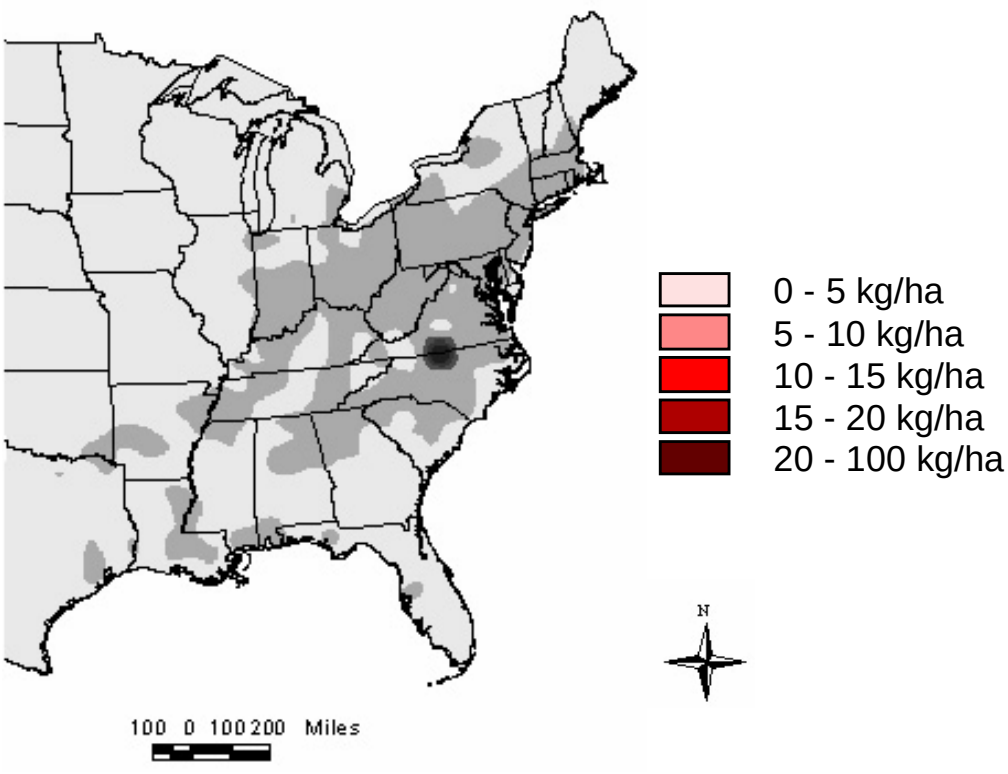


Figure C-34
Annual Nitrogen Deposition
2010 Post CAAA Scenario



Estimating the Effects of the CAAA on Sulfur Dioxide, Oxides of Nitrogen, and Carbon Monoxide

Future-year Pre- and Post-CAAA ambient SO_2, NO, NO_2, and CO concentrations were estimated by adjusting 1990 concentrations using future-year to base-year emissions ratios. The methodology for calculating and applying these ratios is described below. The resulting future-year concentration also are discussed in this section; histograms are used to illustrate the relationship between Post- and Pre-CAAA emissions estimates.

Methodology for Estimating Future-Year SO_2, NO, NO_2, and CO Concentrations

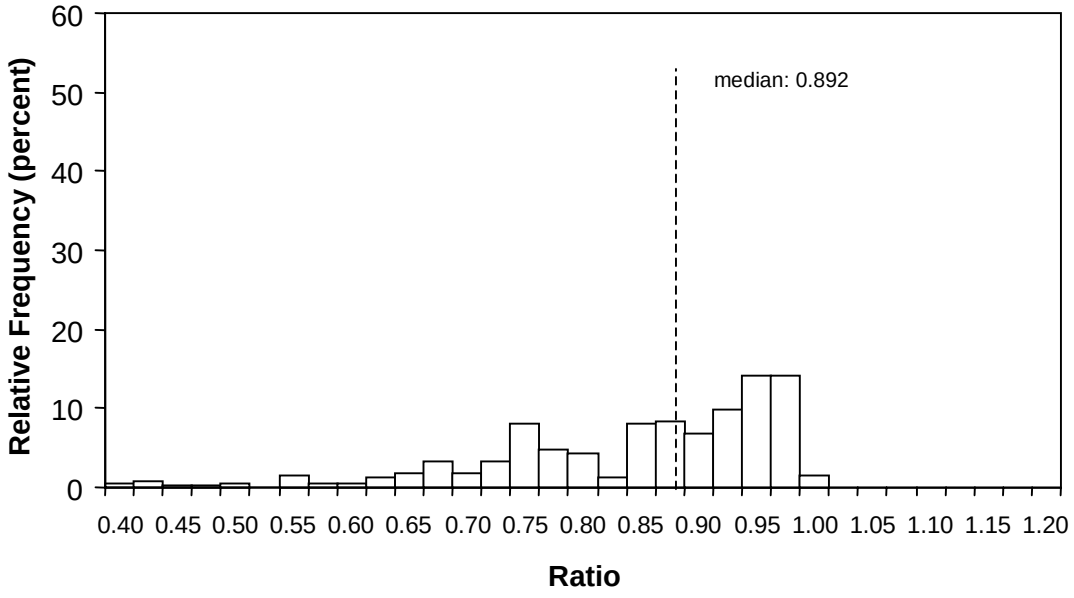
To estimate future-year SO_2, NO, NO_2, and CO concentrations, adjustment factors were calculated using grid cell specific REMSAD emissions data (Douglas et al., 1999). REMSAD's domain encompasses the 48 contiguous states and is divided into 4,950 grid cells, each measuring approximately 56 km by 56 km. As part of the model's input, gridded emission inventories containing seasonal Pre- and Post-CAAA SO_2, NO, NO_2, and CO emissions estimates were prepared. These same emissions estimates used as REMSAD input in other parts of this prospective analysis, were also used to calculate SO_2, NO, NO_2, and CO adjustment factors.

Before emission-based ratios (adjustment factors) were calculated, two separate inventories maintained individually for REMSAD modeling purposes, one containing elevated point source emissions data and the other containing emissions data for low-level sources, were combined. Each stack corresponding to an elevated point source was assigned to a grid cell based on location. Emissions from elevated point sources were then added to the low-level emissions corresponding to the grid cell in which the stack is located. In this manner, a file containing total emissions for each grid cell was prepared. This was done for each season for the 1990 base year and 2000 and 2010 Pre- and Post-CAAA scenarios.

Once the emissions inventory was prepared, emission-based ratios for SO_2, NO, NO_2, and CO were generated. For each RADM grid cell, adjustment factors were calculated comparing future-year (2000 and 2010) emissions under each projection scenarios to base-year (1990) emissions. Separate sets of ratios were developed for each season.

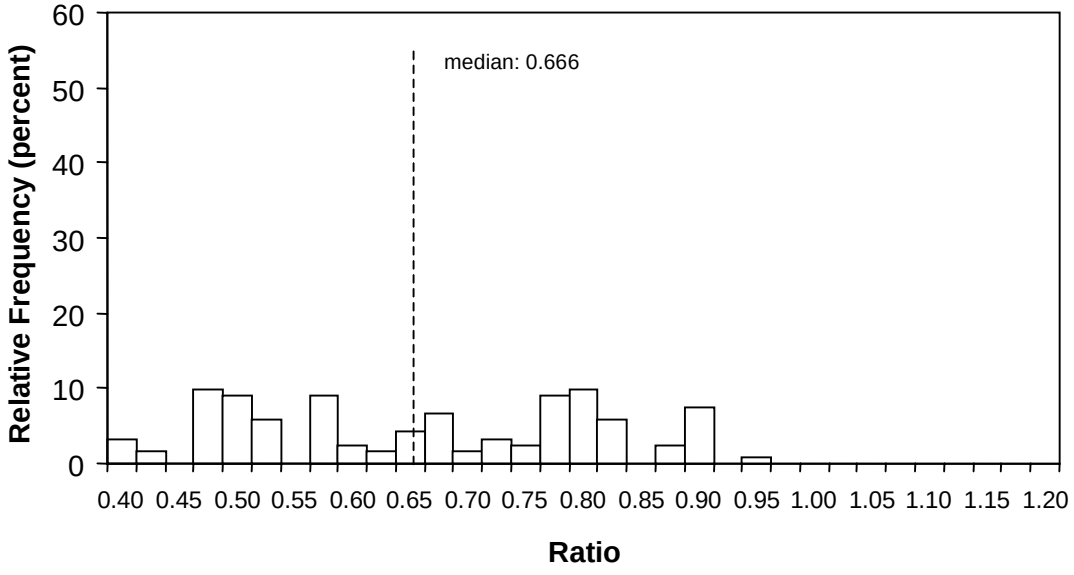
Following the calculation of emission-based ratios, future-year concentrations were then estimated by applying these ratios to observed 1990 base-year monitor concentrations. For REMSAD grid cells without 1990 monitor concentration data interpolation was used to estimate base-year concentrations. Adjustment factors for the grid cell were then applied to the interpolated values.

Figure C-35. Distribution of Monitor-Level Ratios of Summer SO_2 Emissions: 2010 Post-CAAA / 2010 Pre-CAAA



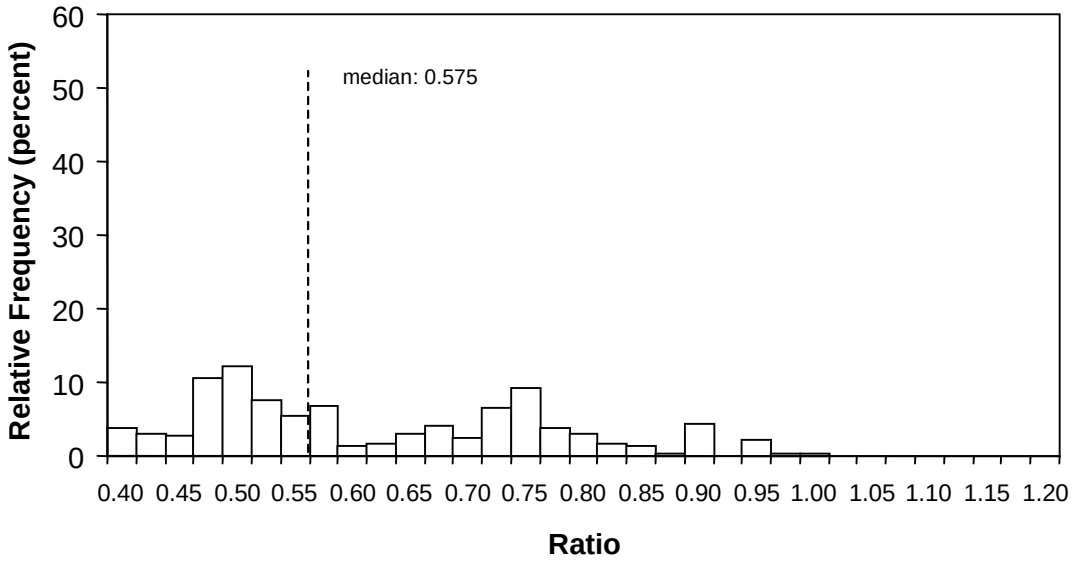
Note: 2.4 percent of the distribution of ratios is less than 0.40.

Figure C-36. Distribution of Monitor-Level Ratios of Summer NO Emissions: 2010 Post-CAAA / 2010 Pre-CAAA



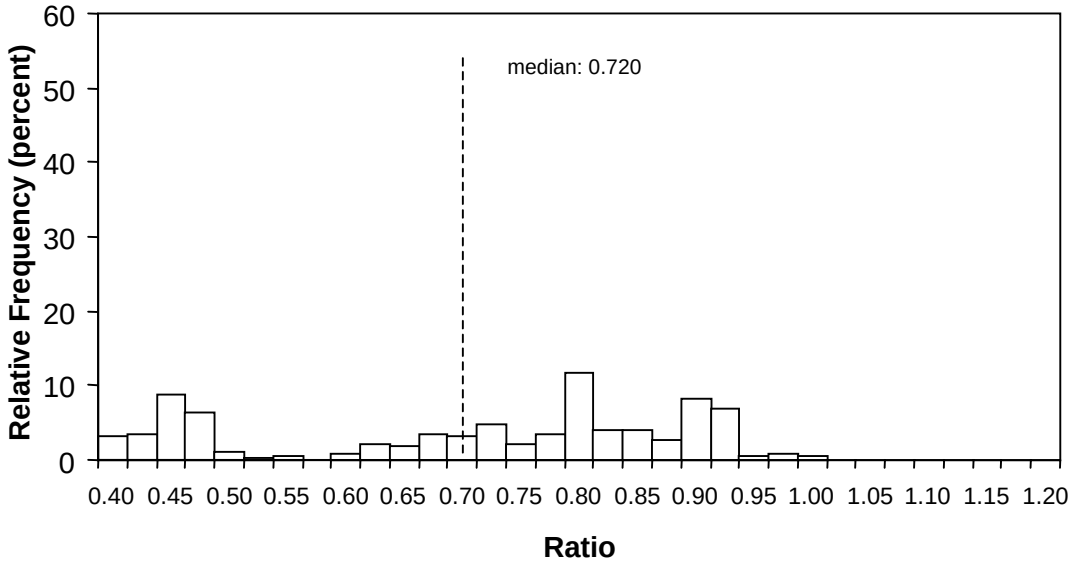
Note: 3.3 percent of the distribution of ratios is less than 0.40.

Figure C-37. Distribution of Monitor-Level Ratios of Summer NO_2 Emissions: 2010 Post-CAAA / 2010 Pre-CAAA



Note: 2.7 percent of the distribution of ratios is less than 0.40.

Figure C-38. Distribution of Monitor-Level Ratios of Summer CO Emissions: 2010 Post-CAAA / 2010 Pre-CAAA



Note: 15.7 percent of the distribution of ratios is less than 0.40.

Emission-Based Ratios for SO_2, NO, NO_2, and CO

Emission-based ratios were calculated for each grid cell, regardless of whether or not the cell contained a monitoring site. The figures included in this section however, represent the distribution of ratios for actual monitoring site locations. These distributions reveal the relationship between future-year and base-year concentrations. A ratios greater that one indicates an increase in ambient concentration from the base-year, while a ratio less than one indicates a decrease.

Our results indicate that compared to the base-year, future-year concentrations of SO_2, NO, NO_2, and CO tend to increase under the Pre-CAAA scenario, while Post-CAAA concentrations for all four pollutants except SO_2 tend to decrease. For example, the median 2010 Pre-CAAA emission-based ratio for SO_2 is roughly 1.35, indicating an increase in median 2010 Pre-CAAA SO_2 concentration of approximately 35 percent from the 1990 base-year. The median ratios for NO, NO_2, and CO are roughly 1.13, 1.17, and 1.05 respectively. Under the Post-CAAA scenario we estimate that in 2010 NO, NO_2, and CO concentrations will tend to be approximately 25 and 30 percent below base-year levels. The median 2010 Post-CAAA emission-based ratios for these three pollutants are roughly 0.74, 0.70, and 0.76 respectively. We estimate that SO_2, concentrations, however, will increase in many areas of the U.S. The median adjustment ratio for this pollutant is approximately 1.21.

Comparison of the Pre- and Post-CAAA Ratios

Comparison of Pre- and Post-CAAA emission-based adjustment factors also helps illustrate the effect of the 1990 Amendments on ambient pollution concentrations. The ratio of 2010 Post-CAAA adjustment factors to 2010 Pre-CAAA adjustment factors shows the impact of the 1990 Amendments on ambient concentrations relative to the baseline scenario. Ratios less than one indicate that we estimate that future-year concentrations of SO_2, NO, NO_2, and CO are lower under the Post-CAAA scenario than under the Pre-CAAA scenario.

Figures C-35 through C-38 show the distribution of 2010 Post-CAAA to 2010 Pre-CAAA ratios for summertime SO_2, NO, NO_2, and CO respectively. These figures illustrate the regional variation in the influence of the 1990 Amendments on ambient concentrations of these pollutants. Although we estimate concentrations in some areas will increase under the Post-CAAA scenario relative to Pre-CAAA estimates, the median summertime 2010 Post- to Pre-CAAA ratios for SO_2, NO, NO_2, and CO are 0.90, 0.67, 0.58, and 0.72 respectively. These values, each less than one, indicate that the central tendency for summertime 2010 Post-CAAA concentration estimates of these four pollutants is to be lower than 2010 Pre-CAAA estimates.

Table C-14 displays the median values of the distribution of Post- to Pre-CAAA ratios for the summer months described above and the remaining three seasons. Just as for the summer; spring, autumn, and winter median values are less than one. Averaged over all four seasons, we estimate a median reduction in SO_2, NO, NO_2, and CO concentrations of approximately 9, 33, 40, and 25 percent respectively. RACT requirements, tailpipe emissions standards, and NO_x emissions trading account for the bulk of the reduction in NO and NO_2 concentrations. Title I nonattainment area controls and Title II motor vehicle provisions are responsible for much of the change in CO concentrations, while regulation of utility and motor vehicle emissions account for majority of the decrease in SO_2 concentrations.

Table C-14
Median Values of the Distribution of Ratios of 2010 Post-CAAA/Pre-CAAA Adjustment Factors

	SO_2	NO	NO_2	CO
Spring	0.904	0.669	0.598	0.790
Summer	0.892	0.666	0.575	0.720
Autumn	0.916	0.677	0.614	0.756
Winter	0.924	0.686	0.626	0.692

Table C-15
Background Concentrations used to Prepare the SO_2, NO, NO_2, and CO Profiles

Pollutant	Background Concentration
SO_2	0
NO	0
NO_2	0
CO	0.2 ppm

Attributes and Limitations of the Modeling Analysis Methodology

The Section 812 prospective modeling analysis utilized a set of modeling tools and input databases that for the most part had been developed, tested, and evaluated as part other modeling studies (e.g., OTAG, SIP modeling analyses, etc.). This provided a cost-effective means of conducting a national-scale modeling exercise. The models used for the study are among the most widely used and evaluated tools for ozone and PM modeling, and have been used for previous regulatory applications. The modeling was performed in manner that is consistent with established practice and EPA guidelines regarding air quality model applications.

Although appropriate techniques were used for the analysis of each pollutant, use of separate models/techniques for the analysis of ozone, PM, and the other criteria pollutants does not allow a fully integrated analysis of the effects of each. Consequently, the results do not reflect all potential interactions between pollutants (e.g., ozone and PM). Ongoing research involving the development and testing of integrated modeling tools (by EPA and other organizations) may provide the opportunity for fully integrated future Section 812 prospective modeling efforts.

Analysis of the effects on the national scale (the CAAA applies to the entire nation) required the use of several different domains with varying grid resolution as well as the use of relatively coarse resolution for many areas of the country for the grid-based modeling effort. The use of relatively coarse grid resolution (12 km and greater) is a potentially important source of uncertainty with respect to the modeling results. Previous studies have found that the response of the UAM-V modeling system to emission reductions is affected by grid resolution (Douglas et al., 1996). Thus, the use of grid-cell specific adjustment factors to modify site-specific data may introduce some uncertainty into the future-year estimates.

There are always uncertainties associated with the use of modeling results to estimate future-year air quality. These derive from inaccuracies in the model inputs and/or model formulation and were manifested in this study in the evaluation of model performance. While good model performance was

achieved for most model applications, ozone concentrations were underestimated within the Los Angeles domain and PM concentrations were underestimated during the fall and winter simulation periods in the REMSAD application. RADM/RPM, used as part of the PM and visibility analyses, showed a tendency to overestimate annual average sulfate concentrations and warm season nitrate concentrations. Annual average nitrate predictions generated by RADM/RPM, however, matched air quality monitor data.

The acid deposition estimates included in the present analysis are limited to the eastern states within the RADM domain. Deposition in the western U.S. was not modeled for this study. Although acid deposition is a problem primarily for the eastern U.S., deposition does occur in states west of the RADM domain. The magnitude of the benefits of reducing acid deposition in these western states is likely to be small, however, relative to the overall benefits associated with the Clean Air Act Amendments.

The approach used in this study to estimate future air quality (the combined use of observed data and modeling results) may, compared to a more standard air quality model application (e.g., a model application for attainment demonstration purposes), tend to minimize the effects of many of the uncertainties mentioned in this section. The reason for this is that the modeling results are used in a relative sense, rather than an absolute sense. This may enhance the reliability of the future-year concentration estimates, especially in the event that the uncertainty inherent in the absolute concentration values is greater than that associated with the response of the modeling system to changes in emissions.

The ratios for adjusting the observed data are calculated using modeling results for a limited number of simulation days and it is assumed, using this methodology, that the ratios can be used to represent longer time periods. This approach permits the estimation of seasonal and annual concentration distributions. Nevertheless, the use of the model-based ratios in adjusting data for an entire season or year may result in some over- or underestimation of the benefits of the simulated control measures, depending upon whether the simulation results for the modeled days are sufficiently representative of the meteorological and air quality conditions that occurred during 1990.

Finally, there are numerous ways in which the adjustment factors could be calculated and applied. The approach used in this study was designed to make the best use of the information and level of detail present in both the observations and the modeling results (e.g., use of decile and quintile based ratios for ozone and PM, respectively). The specific assumptions employed in the application of the methodology, however, may affect the resulting air quality profiles and should be carefully considered in the subsequent use and interpretation of the results.

Conclusions and Recommendations for Further Research

The results from the air quality modeling component of the Section 812 prospective analysis indicate that for both future years (2000 and 2010), the measures and programs associated with the CAAA are expected to result in lower concentrations of ozone, PM, and the other criteria pollutants compared to a future-year scenario without such programs. The degree of improvement in air quality varies among the criteria pollutants and the various portions of the country included in the modeling analysis. The results also differ between the two future years, such that the improvements are greater and more widespread for 2010.

The modeling analysis relied on a set of modeling tools and input databases that (for the most part) had been developed, tested, and evaluated as part other modeling studies. It also made use of several of the most widely used and comprehensively tested tools for ozone and PM modeling. The modeling was performed in a manner that is consistent with established practice and EPA guidelines regarding air quality model applications. However, as noted in the

previous section of this report, there are several features of the modeling analysis that could be improved upon, especially considering recent advances in the development of integrated modeling tools and techniques. Recommendations for future air quality modeling efforts to support the Section 812 prospective analyses include:

- Selection of modeling episode periods using an integrated episode selection procedure (e.g., Deuel and Douglas, 1998) such that the modeling periods are representative of the historical meteorological and air quality conditions and can be used to represent seasonal and annual ozone, PM, and visibility metrics

- Reconfiguration of the modeling domain(s) such that a consistent use of high-resolution grids over urban areas with complex meteorological or emissions-based features are accommodated.

- Review and update of the input data and input preparation techniques to include, for example, updated (more recent) emissions estimates (anthropogenic and biogenic), higher-resolution meteorological inputs, enhanced estimates of future land-use patterns (reflecting growth of urban areas, changes in the interstate transportation networks, etc.).

- Use of an integrated modeling tool for the simultaneous analysis of the effects of emissions changes on ozone, PM, and other pollutants (several tools, including MODELS-3 and UAM-VPM, are currently undergoing development and testing). A comprehensive evaluation of model performance will be required.

- Continued review and enhancement (as appropriate) of the methodology for the combined use of observed data and modeling results.

References

BAAQMD. 1998. "Bay Area – North Central Coast Photochemical Modeling Investigation of Ozone Formation and Transfer" available electronically at: http://sparc2.baaqmd.gov/MontereyPrj/MontereyPrj.html.

Binkowski, F.S. and U. Shankar. 1995. "The Regional Particulate Matter Model 1. Model description and preliminary results." *J. of Geophysical Research*. 100: 26,191-209.

Chang, J.S., R.A. Brost, I.S.A. Isaksen, S. Madronich, P. Middleton, W.R. Stockwell, and C.J. Walcek. 1987. "A Three-Dimensional Eulerian Acid Deposition Model: Physical Concepts and Formulation." *J. of Geophysical Research*. 92: 14,681-700.

Chang, J.S., P.B. Middleton, W.R. Stockwell, C.J. Walcek, J.E. Pleim, H.H. Lansford, F.S. Binkowski, S. Madronich, N.L. Seaman, and D.R. Stauffer. 1990. "The Regional Acid Deposition Model and Engineering Model". NAPAP SOS/T Report 4. In: *Acidic Deposition: State of Science and Technology, Volume 1*. National Acid Precipitation Assessment Program, Washington D.C., December.

Dennis, R.L., W.R. Barchet, T.L. Clark, and S.K. Seilkop. 1990. "Evaluation of Regional Acid Deposition Models (Part I)." NAPAP SOS/T Report 5. In: *Acidic Deposition: State of Science and Technology, Volume 1*. National Acid Precipitation Assessment Program, Washington, D.C., September.

Dennis, R.L., J.N. McHenry, W.R. Barchet, F.S. Binkowski, and D.W. Byun. 1993. "Correcting RADM's sulfate underprediction: Discovery and correction of model errors and testing the corrections through comparisons against field data." *Atmospheric Environment*. 27A(6): 975-997.

Dennis, R. 1995. "Estimation of Regional Air Quality and Deposition Changes Under Alternative 812 Emissions Scenarios Predicted by the Regional Acid Deposition Model, RADM." Draft Report for U.S. Environmental Protection Agency. ORD/NERL. October.

Dennis, R.L. 1997. "Using the Regional Acid Deposition Model to Determine the Nitrogen Deposition Airshed of the Chesapeake Bay Watershed." *Atmospheric Deposition to the Great Lakes and Coastal Waters*. Ed. J.E. Baker, Society of Environmental Toxicology and Chemistry, Pennsacola, FL: 393-413.

Deuel, H. P, N. K. Lolk, and S. G. Douglas. 1996. "Preparation of Air Quality and Other Inputs for Application of the UAM-V Model for the 1-15 July 1988 OTAG Modeling Episode." Systems Applications International, Inc., San Rafael, California (SYSAPP-96/51).

Deuel, H. P, and S. G. Douglas. 1998. "Episode Selection for the Integrated Analysis of Ozone, Visibility, and Acid Deposition for the Southern Appalachian Mountains." Systems Applications International, Inc., San Rafael, California (SYSAPP-98/07r1).

Douglas, S. G., J. L. Fieber, A. B. Hudischewskyj, and J. L. Haney. 1994. "Photochemical Modeling of the Maricopa County Ozone Nonattainment Area." Systems Applications International, Inc., San Rafael, California (SYSAPP-94/079).

Douglas, S. G., N. K. Lolk, and J. L. Haney. 1996. "Investigation of the Effects of Horizontal Grid Resolution on UAM-V Simulation Results for Three Urban Areas." Systems Application International, Inc., San Rafael, California (SYSAPP-96/65).

Douglas, S.G., R. Iwamiya, G. Mansell, H. Tunggal, and C. van Landingham. 1999. "Air Quality Modeling to Support the Section 812 Prospective Analysis". ICF Kaiser Consulting Group, Systems Applications International, Inc., San Rafael, California (SYSAPP-99/09).

External Review Panel. 1994. "Report on RADM Evaluation for the Eulerian Model Evaluation Field Study Program." Ed. Anton Eliassen. Norwegian Meteorological Institute, Norway.

Langstaff, J. E., S. Eberly, and K. A. McAuliffe. 1994. "Retrospective Analysis of SO_2, NO_x, and CO Air Quality in the United States." Systems Application International, Inc., San Rafael, California.

Langstaff, J. E., and M. E. Woolfolk. 1995 "Retrospective Analysis of PM Air Quality in the United States." Systems Application International, Inc., San Rafael, California.

McHenry, J.N. and R.L. Dennis. 1994. "The Relative Importance of Oxidation Pathways and Clouds to Atmospheric Ambient Sulfate Production as Predicted by the Regional Acid Deposition Model." *Journal of Applied Meteorology*. 33(7): 890-905.

OTAG. 1997. OTAG Regional and Urban Scale Modeling Workgroup. Modeling Report. Version 1.1."

Pechan. 1998. "Emission Projections for the Clean Air Act Section 812 Prospective Analysis." E. H. Pechan and Associates.

Pitchford, M.L. and W.C. Malm. 1994. "Development and applications of a standard visual index." Presented at the Conference on Visibility and Fine Particulates, Vienna, Austria. *Atmospheric Environment*. (28): 1055-63.

SAI. 1990. "User's Guide for the Urban Airshed Model, Volume I: User's Manual for UAM (CB-IV). U.S. Environmental Protection Agency (SP-450/4-90-007b; NTIS No. PB91-13235).

SAI. 1992. "User's Guide for the Urban Airshed Model, Volume IV: User's Manual for the Emissions Preprocessor System 2.0". U.S. Environmental Protection Agency, (EPA-450/4-90-007D), May 27, 1992.

SCAQD. 1994. "Ozone Modeling – Performance Evaluation." Draft Technical Report V-B. South Coast Air Quality Management District, Diamond Bar, California.

SCAQD. 1996. "1997 Air Quality Management Plan." South Coast Air Quality Management District, Diamond Bar, California.

U.S. Environmental Protection Agency. 1991. "VOC/PM speciation Data Base Management System (SPECIATE), Version 4.1." Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina (EPA-450/4-91-027).

U.S. Environmental Protection Agency. 1995. "Acid Deposition Standard Feasibility Study Report to Congress." Office of Air and Radiation, Acid Rain Division, Washington, D.C. (EPA-430/R-95-001a).

U.S. Environmental Protection Agency. 1997. "Deposition of Air Pollutants to the Great Waters." Office of Air Quality Planning and Standards, Research Triangle Park, NC (EPA-453/R-97-011).